Prof. W. M. Davis
with kind regards
I. C. Russell

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
J. W. POWELL DIRECTOR

A
GEOLOGICAL RECONNAISSANCE
IN
SOUTHERN OREGON

BY

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EXTRACT FROM THE FOURTH ANNUAL REPORT OF THE DIRECTOR—1882-83

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

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By Israel C. Russell.

INTRODUCTION.

The area of interior drainage lying between the Rocky Mountains and the Sierra Nevada, known as the "Great Basin," extends northward of the Nevada-Oregon boundary for about 160 miles, and embraces not far from 16,000 square miles of the central and southern portions of Oregon. On the east and north it is bounded by the immense hydrographic basin of the Columbia River, and on the west by the drainage systems of the Klamath and Pitt rivers. The immediate drainage on the eastern border is into the Owyhee and Malheur rivers; these are tributary to the Shoshone, one of the largest branches of the Columbia. The country northward of this prolongation of the Great Basin delivers its drainage into the Des Chutes and John Day rivers, which flow northward and join the Columbia just before it commences its rugged passage through the Cascade Mountains. Nearly all the drainage of the arid region south of the Nevada-Oregon boundary finds its way southward to the Black Rock and Carson deserts, once covered by the waters of Lake Lahontan, and is there evaporated. The region to be described in this paper includes all of the area of interior drainage north of the hydrographic rim of Lake Lahontan.

The boundaries of the Great Basin in Oregon are not hard and fast lines, determined throughout by the crests of mountain ranges, but are indefinite in places, and change with the alternation of humid and arid periods. For example, during the past few years the ratio of precipitation to evaporation has not been sufficiently great to cause Goose Lake to overflow—and we have therefore included it on our map within the rim of the Great Basin;—but its normal condition is that of a fresh-water lake with outlet, its discharge being through Pitt River into the Sacramento. The former outlet of Malheur Lake, to the northeast, was across a very low divide, that would furnish an escape for the lake should its waters rise even to a very moderate height. In case of such an event the Malheur Basin would become tributary to the Shoshone, and the eastern rim of the Great Basin in this part of its course would be carried

ROUTE OF TRAVEL.

Our reconnaissance commenced at the head of Quinn River, Navada, a few miles north of Camp McDermit, and was carried northward and westward into southern Oregon so as to cross the country within the rim of the Great Basin, that was most likely to afford information in regard to questions concerning Quaternary geology.

Throughout the journey I was accompanied by Mr. Willard D. Johnson, of Washington, D. C., to whom I am indebted for the compilation of the accompanying map, as well as for much general assistance while conducting field work. (*a*)

From the headwaters of Quinn River we crossed the divide to the westward, and visited Alvord Lake; and thence traveled northward through the narrow valley that follows the eastern base of the Stein Mountains. After crossing this range at Summit Spring we descended into the hydrographic basin of Malheur Lake, and continued our journey northward as far as Fort Harney.

The Stein Mountains, rising from 4,000 to 5,000 feet above Alvord Lake, afford the boldest and most conspicuous topography in Southeastern Oregon and exceed most of the Basin Ranges in grandeur of scenery. During our entire journey their snowy summits were seldom out of view. They present eastward a bold palisade face, formed of the faulted edges of stratified volcanic layers, which from the valley appear as even in their bedding as if they were of sedimentary origin.

The remarkable stratification of the volcanic rocks of Central and Southern Oregon was observed by Dr. Newberry during his reconnaissance along the eastern base of the Cascade Mountains; (*b*) and also by Dr. James Blake while examining the structure of the "Puebla" (Pueblo) Mountains, (*c*) which are a continuation southward of the Stein Mountain range. When the time comes for the thorough study of the vulcanology of Southern Oregon, the Stein Mountains will furnish a suitable initial point of the investigation.

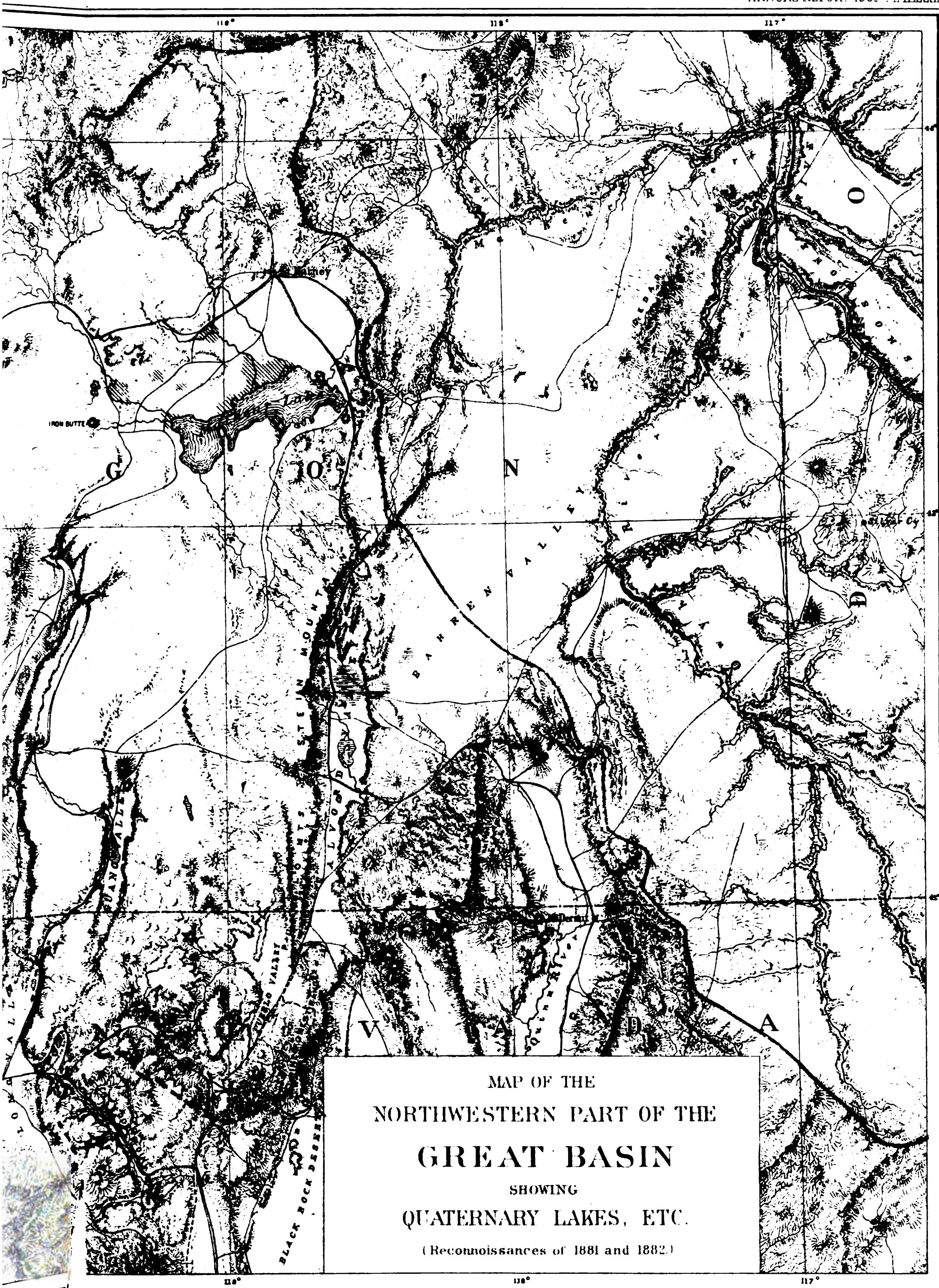
Standing on an isolated peak near Summit Spring, on the pass across the northern end of the Stein Mountains, the observer has a magnificent view, in every direction, of the broken volcanic region that surrounds him, and especially of the deeply-eroded country to the north

a The topographic map forming the base of plates LXXXIII and LXXXIV, was compiled from the published surveys of the U. S. Engineer Corps, with the addition of topographical sketches made during the present reconnaissance.

b Pacific Railroad Reports, Vol. VI.

c Proc. California Acad. Sci., vol. 5, p. 210.

W D. Johnson, Topographer



Julius Bien & Co. lith. I. C. Russell, Geologist.

Scale one inch = Twenty-four miles
48 72 94 120

and east, drained by the Owyhee and Shoshone rivers. From this volcanic summit one can see in profile the immense tilted block from which the rugged crest of the Stein Mountains has been sculptured. The region along the immediate eastern base of the range is one of diverse displacement; but a section taken at the playa north of Lake Alvord shows the simplicity of the mountain structure, as is indicated in the following diagram: (a)

FIG. 6.—Sketch-section of Alvord Valley, Oregon.

To the westward the slope of the range is moderate, and merges gently into the broad desert plain of the Malheur Basin, while the eastern face presents an inaccessible precipice 4,000 or 5,000 feet high.

A narrow belt of country to the eastward of the northern part of the Stein Mountains is extremely rugged and difficult to traverse, owing to the abruptness of the upturned edges of the long, narrow blocks into which it has been broken. The fault-lines that determine this topography are branches of the great fault along the eastern base of the main range, and trend approximately north and south.

A bird's-eye view of the surrounding country about the Stein Mountains impresses one forcibly with the fact that the entire region was at one time a vast volcanic table-land, which has been broken by north and south fault-lines, and the intervening blocks tilted at diverse angles. The displacements occurred so recently that the subsequent period of erosion has been insufficient to wear down the scarps, or to fill the depressed areas.

In a broad view of the region drained by the Owyhee and Shoshone Rivers, it is to be observed that the Basin Range structure is there wanting, and the volcanic table-land, instead of being broken by almost innumerable fault-lines, as in the central portion of the Great Basin, is cut by a labyrinth of eroded cañons that conduct the drainage to the ocean.

The rugged and broken character of this land of black volcanic rocks is the more marked because it is unclothed with vegetation. The Stein Mountains, north of their usually snow-clad peaks, are covered with a scattered growth of cedars; but the rest of the country, as far as the eye can distinguish, receives its color solely from the somber rocks, or has the ashen-gray and russet-brown colors of the desert. The only relief from the dark and motionless landscape is the silvery luster of the

a In this and similar sections that follow, the vertical scale is exaggerated and no attempt is made to represent the structure of the orographic blocks. The volcanic strata forming the mountains are indicated by heavy broken lines, usually inclined, and the Quaternary lake-beds filling the valleys by fine horizontal lines.

waving bunch-grass. The visitor to these barren regions in early spring will be surprised to find them bright with lowly blossoms, and the air, even on the sage-brush deserts, sweet with delicate perfume. The life of the desert flowers is short, however, and their incense quickly wanes as the increasing heat changes the vernal tints to brown and grey.

To the north and northwest is a vast stretch of volcanic ridges, mesas, and barren valleys, bounded on the far-distant horizon by snow-capped peaks. When the atmosphere is clear, one may distinguish Strawberry Butte, the most northerly point on the rim of the Great Basin. In the view westward the eye follows the gentle slope of the Stein Mountains until they merge into the Malheur Desert, on which stand mesas and crumbling rock piles, forming isolated buttes. Thirty miles away, in the center of the featureless plain, the eye catches the glimmer of the waters of Malheur Lake, while far beyond are indefinite mountain peaks, lone buttes, and table-lands, veiled in desert haze. It was through this region that our subsequent travels led us.

From Fort Harney our reconnaissance was carried westward, with a fairly good road to follow until the crossing of Silver Creek was reached. From that point we traversed the open country, without road or trail of any kind, to the Glass Buttes; whence our course led southwestward to Silver Lake, as indicated by the route of travel shown on plate LXXXIII.

The country traversed by this portion of our journey was a rough and irregular basaltic table-land, covered with bunch-grass and a scattered growth of cedars. The stream-beds were few, and usually dry; our sole source of water being the "water-pockets" in the surface of the basalt, which in spring and early summer are sufficiently abundant to meet the traveler's needs. The more prominent peaks scattered over the region are known as Iron, Glass, and Pyramid buttes, Wagon-tire Mountain, etc. These are isolated hills, usually conical, that rise from 1,000 to 2,500 feet above the surrounding country, and are barren, or scantily clothed with cedars. In all cases the buttes are of volcanic origin, and, from their conical form, appear, at least in some instances, to be the ruins of ancient volcanoes. The Glass Buttes were found to be composed of rhyolite, together with large quantities of obsidian, or volcanic glass. No evidence that they were once volcanic craters was observed; and no basaltic overflows, or other phenomena, were seen to indicate that they had recently been centers of volcanic action. On weathering, the obsidian becomes coated with a silvery film, having a bright metallic luster, that occurs in bands and develops an incipient lamination in the glass. Throughout the region in which these isolated peaks are found, the Basin Range structure is obscure or wanting; the topographical forms indicating other, and probably older, conditions. The prominent features are due mainly to erosion and to the extravasation of volcanic material, and not to the tilting of orographic blocks.

As these isolated buttes are far removed from settlements, and can only be reached by a tedious journey across a rough and desert country,

they have retained their primitive wildness, and are still the home of antelope, deer, and mountain sheep. To the sportsman they are as attractive as any locality known to us in the Far West.

From Silver Lake our explorations led us southward along the bold western shore of Summer Lake, and thence through the extremely rugged region embracing the Chewaucan Marsh, Abert Lake, Goose Lake, and the Warner Lakes. The wild and all but impassable character of this remarkable lake region renders it difficult of exploration, but at the same time of great geological interest. The ruggedness of its topography, and the abruptness of the precipices enclosing the valleys, are mainly due to orographic displacement. The numerous fault-scarps form precipitous palisades across the country, from a few hundred to 1,500 or 2,000 feet in height, trending approximately north and south, and sometimes unbroken by passes for a distance of 50 miles. The depressed blocks give rise to rock-basins, some of which are occupied by lakes, that mirror on their placid bosoms the rugged grandeur of the surrounding walls. A few of the lakes are remnants left after long concentration by evaporation; while others, of even greater interest, are fresh, or nearly fresh, but occupy ancient basins from which the waters have never overflowed. The mountain-ridges overlooking this wild region are dark with pine and spruce, the lower slopes are scantily clothed with cedars, and on the sage-covered valleys trees are entirely wanting. The uplands and plains alike abound in game. This lake-region is not only remarkable for the ruggedness of its scenery, but furnishes a unique example of displacement on a grand scale, and at such a recent date that the fault-scarps still form beetling cliffs, that appear to have been upraised but yesterday.

In journeying southward from the Warner Lakes, we followed Long Valley, another north and south orographic depression, structurally a continuation of the valley holding the Warner Lakes. At the southern end of Long Valley, we crossed a low divide just south of the Massacre Lakes, and entered High Rock Cañon, which thirty years ago was one of the highways to California, but has since been abandoned by travelers, and is now rendered nearly impassable by fallen rocks and stream erosion. Our journey was continued down this deep water-cut gorge, with high walls of rhyolite on either hand, until we emerged from a lofty gate-way, and looked down upon an absolutely barren country, forming a part of the Black Rock Desert. High Rock Cañon is partially filled with alluvium, through which a little brook meanders, at times losing its identity in swampy meadow-lands. Throughout the gorge there is abundant evidence that this was formerly the channel of a considerable stream, probably dating back to Tertiary times, while during the Quaternary it must have been tributary to Lake Lahontan. The greater part of the country immediately south of the Nevada-Oregon boundary falls within the hydrographic basin of Lake Lahontan, and will demand attention when the history of that lake is written.

DISPLACEMENTS.

Geological investigations have shown that the rocky strata composing the earth's crust have frequently been broken, and that the beds on the opposite sides of the lines of fracture have been mutually displaced. Such fractures and displacements are called "*faults.*" The following section, taken at right angles to the plane of faulting, illustrates a simple displacement that is unaccompanied by secondary disturbances. In this illustration the beds have been sheared, or broken, along a single plane, indicated by the line x—y, and one side has been depressed below its original position:

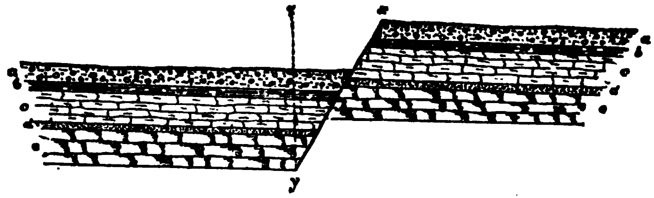


FIG. 7.—Ideal section of faulted beds.

In speaking of faults the term "*throw*" is used to indicate the amount of vertical displacement between the broken edges of the beds on the opposite sides of the plane of fracture. Sometimes the words "*downcast*" and "*displacement*" are used in the same sense. The throw may vary from a few inches, or even fractions of an inch, to many thousands of feet. The side of the fault that is highest is termed the "*heaved*" side and the opposite the "*thrown*" side. The masses bounded by faults are termed "*orographic blocks.*" The fractures dividing orographic blocks may descend vertically into the rocks, or be inclined at any angle. The angle that the fault-plane makes with a perpendicular plane is known as the "*hade*" of the fault. In the section given above, the hade of the fault is represented by the angle $x\ y\ z$. As an almost invariable rule, the fault-plane inclines toward the thrown block. The direction which a fault takes in crossing a country is called its "*strike.*" That portion of the face of a heaved block that projects above the adjacent thrown block is termed a "*fault-scarp.*" Such a scarp is very commonly removed by denudation, and although a fault may have a throw of perhaps a mile, its presence may be unmarked in the topography of the country. This is the case especially in faults of great antiquity, where the cliff of displacement has been long exposed to the agents of denudation. In the Great Basin many faults are of a comparatively recent

U. S. GEOLOGICAL SURVEY

W. D. Johnson, Topographer

Julius Bien & Co. lith

Scale one inch = Twenty-four miles

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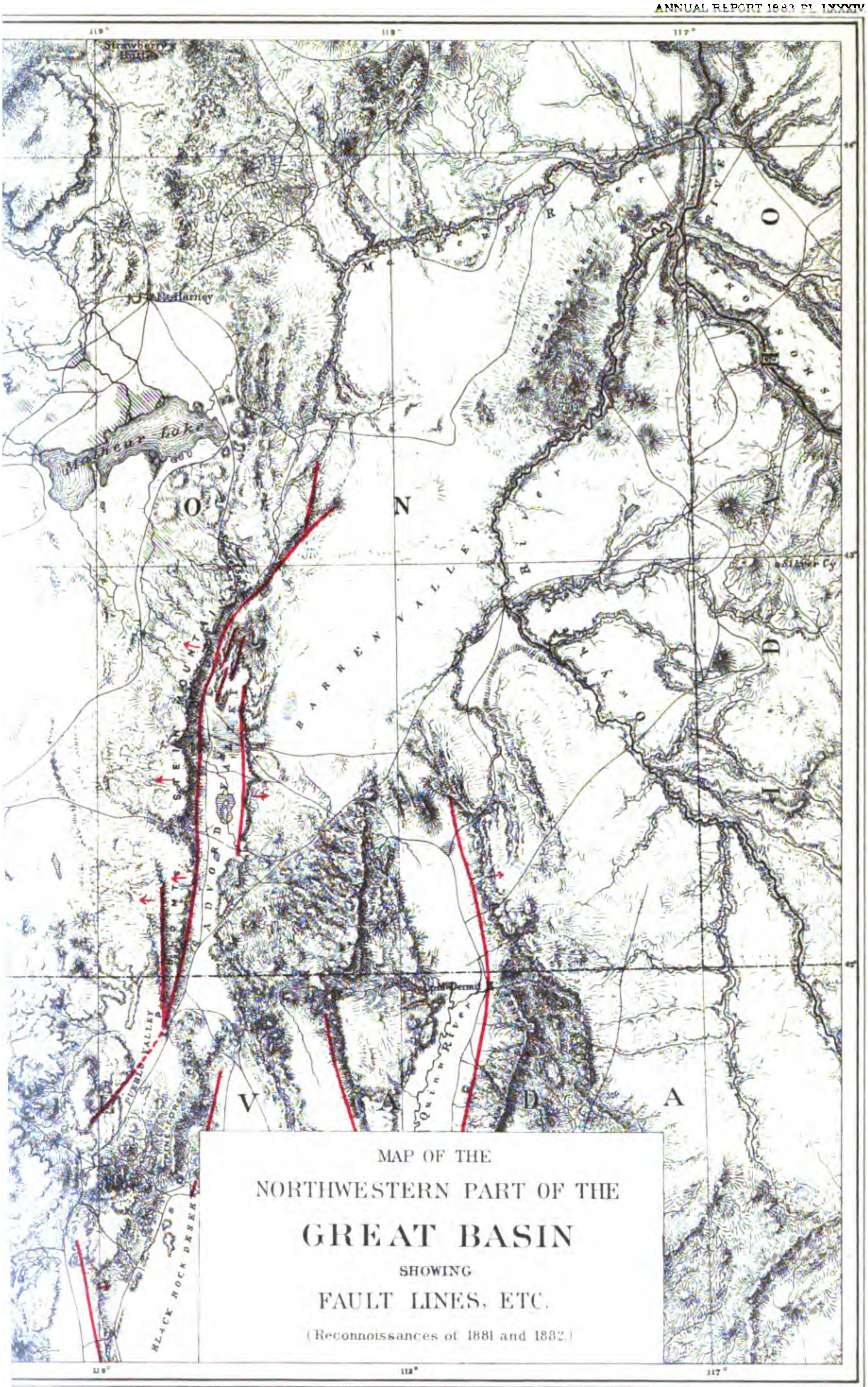


MAP OF THE
NORTHWESTERN PART OF THE
GREAT BASIN
SHOWING
FAULT LINES, ETC.
(Reconnoissances of 1881 and 1882.)

I C Russell, Geologist.

r miles 72 94 120

date, and present bold scarps, that are frequently but slightly scarred by erosion, while the most recent examples of all were unquestionably formed within the past few years, and are yet unclothed by vegetation. These scarps are sometimes several thousand feet high, as is illustrated by the precipitous eastern faces of the Sierra Nevada and Cascade Mountains, or the equally bold western wall of the Wahsatch Range. Fault-scarps vary in height in different parts of their courses; they may be curved, or form sharp salient or re-enterant angles; and in many cases they throw off branches, and divide into a number of smaller faults. In all their features they are characterized by irregularity and want of symmetry.

The whole of the Great Basin thus far explored is remarkable for the persistency of a single type of mountain structure. This is the simplest of orographic forms, and has been already mentioned as a tilted block, bounded by faults. The whole immense region lying between the Sierra Nevada and Rocky Mountain systems has been broken by a multitude of fractures, having an approximately north and south trend, that divide the region into long, narrow, orographic blocks. These have been tilted so as to form small but extremely rugged mountain ranges, often from 50 to 100 miles in length, with a width of but a few miles. This region may be classed as a "zone of diverse displacement" of vast dimensions.(*a*) If we draw across the map of the Great Basin an east and west line touching the southern end of Great Salt Lake, it will intersect not less than twenty lines of profound displacement. Farther south, in the latitude of Sevier Lake, the number of orographic blocks into which the country has been broken is even greater.

As already stated, that part of the Great Basin lying north of the Nevada-Oregon boundary has the same pronounced orographic structure as the main area of interior drainage. In considering the physical history of the Great Basin as a whole, however, we find over a wide area two distinct types of structure, belonging to widely separated periods, and due to forces acting in different directions. During the first period the rocks were plicated and crumpled into anticlinal and synclinal folds; and at the time of the second disturbance the present topography, due to orographic displacement, was initiated. These two periods of orographic movement were recognized by Mr. King, who speaks of the Great Basin as a "region of enormous and complicated folds, riven in later times by a vast series of vertical displacements."(*b*) These two types of structure are apparent at many localities throughout the central portion of the region of interior drainage; but immediately north of the Nevada-Oregon boundary, where the rocks are almost entirely volcanic, we find only such disturbances as are due to faulting. The age of the volcanic beds in the northern extremity of the Great

a For types of displacements consult "Geology of the Uinta Mountains," Powell, pp. 16, 17.

b U. S. Geol. Exploration of the 40th Parallel, Vol. I, p. 735.

Basin would therefore seem to be intermediate between the two periods of disturbance.

The main lines of faulting in Southern Oregon, as well as some of the minor branches, are indicated on the accompanying map (Plate LXXXIV). It is not claimed, however, that this is a complete analysis of the orography of the region; on the contrary, it is the result of a reconnaissance in a country previously unknown geologically, and much of which was unmapped.

THE STEIN MOUNTAINS FAULT.

The first line of displacement claiming our attention is that which determines the eastern face of the Stein Mountains. This fault was first observed at the southern end of Pueblo Valley, Nevada, about 30 miles south of the Oregon line, where it forms, in volcanic tuff and basalt, a scarp a few hundred feet high, bordering Pueblo Valley on the west. Tracing it northward, we find its scarp increasing in height, and forming the bold eastern face of the Pueblo Mountains, which are structurally a continuation southward of the Stein Mountains. As indicated on Plate LXXXIV, the fault branches at the southern end of the Pueblo Mountains, and gives origin to two lines of cliffs, each facing eastward. The western branch has a length of about 20 miles, and trends nearly due north and south. The eastern or main fault, as previously stated, follows the eastern base of the Stein Mountains throughout their entire length. At the northward it branches, the mountains become lower, and finally the great displacement breaks up into a series of lesser faults, that give origin to a narrow zone of broken and tilted blocks. The strike of the main fault is nearly northeast and southwest, but in the northern part it has a marked curvature to the eastward. In Pueblo Valley a generalized section would show a simple line of displacement along the western side of the valley, and another at the eastern base of the Pine Forest Range, which forms its eastern boundary, as is indicated in the following diagram:

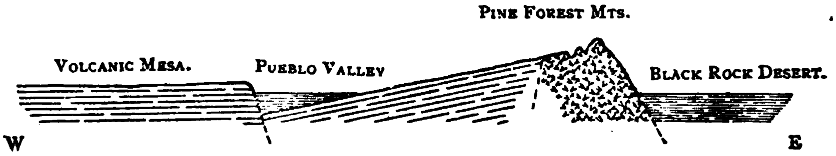


Fig. 8.—Sketch-section of Pueblo Valley, Nevada.

In some places in Pueblo Valley the structure is more complicated than is shown above, owing to a fault along the eastern side of the valley. The eastern face of the Pine Forest Range is composed of granite, and forms a bold mountain fault-scarp, bordering the Black Rock Desert

on the west for a long distance. A sketch section made near the northern end of the Stein Mountains fault shows the displacement to be divided into a number of minor faults, as is indicated below:

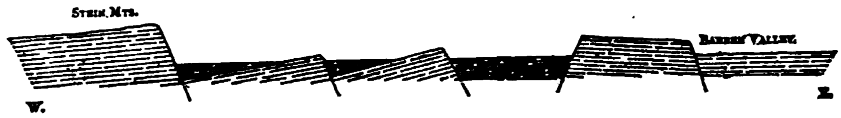


FIG. 9.—Sketch Section across northern end of Stein Mts.

About 20 miles northward of where the above section was taken the fault-scarps become low and obscure, and they were not traced farther. The total observed length of the fault is about 100 miles, with a displacement where the mountains are highest of not less than 5,000 or 6,000 feet. Large hot springs are associated with it in Pueblo Valley, but they do not rise at the immediate base of the fault-scarp. Farther north, however, at the point where the Stein Mountains attain their greatest elevation, there are a number of springs with a temperature of 168° F. that are located not only where the displacement has been greatest, but also where there has been a very recent movement along the old fault. The irregular scarp in alluvium formed by the recent displacement is fresh and unclothed with vegetation, and may be traced for several miles at the immediate base of the mountains, defining the boundary between swampy meadows and solid rock. The hade of the recent fault is to the eastward, at a high angle; while the throw, as shown by the fresh scarp, is from 20 to 50 feet.

The displacement along the eastern base of the Pine Forest Range also shows evidence of a recent movement for a distance of from 40 to 50 miles. A recent fault-scarp in alluvium follows the eastern base of the range and hot springs come to the surface along the line of fracture.

THE WARNER VALLEY FAULT.

The valley of the Warner Lakes and Long Valley to the southward together form a single narrow belt of diverse displacement that is fully 100 miles in length. The exhibition of fault-scarps, tilted blocks, and sunken areas, to be seen at the southern end of the Warner Lakes, is the most interesting of its kind that it has ever been our privilege to examine. In this narrow zone the orographic blocks of dark volcanic rock are literally tossed about like the cakes in an ice-floe; their upturned edges forming bold palisades that render the region all but impassable. The main line of displacement is along the foot of the perpendicular cliffs that border the Warner Lakes on the east. Midway a large branch with reverse throw crosses to the west side of the lakes and gives origin to the high bluffs that extend from Crook's Bridge southward. These fault-scarps rise in sheer precipices that overshadow

the Warner LaLes throughout their entire extent. Towards the northern end of the valley the great fault-scarp forming its eastern wall sends off a number of branches, at quite regular intervals, with a general northwest trend. The blocks thus separated pass under the lake-beds that floor the valley, and appear again on its western border, where they form cliffs of considerable height. Their acute ends are visible at the point of bifurcation; and the apex of a thin wedge of rock clings high on the edge of the great fault-scarp, while its base is buried in the lake-beds in the bottom of the valley. This is but one of the slivers rent off by the great fracture. The great fault-scarp itself finally became lost at the northward in subdivisions.

The country to the north and east is a rough volcanic table-land that has undergone considerable erosion, and indicates the nature of the plateau of which the region of the Warner Lakes formed a part before it was faulted.

The following ideal section represents the orographic structure of the northern part of the valley, except that the minor faults are omitted:

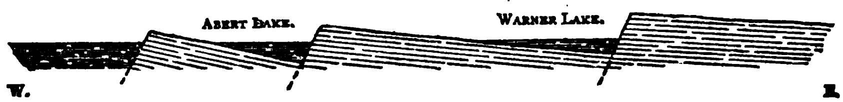


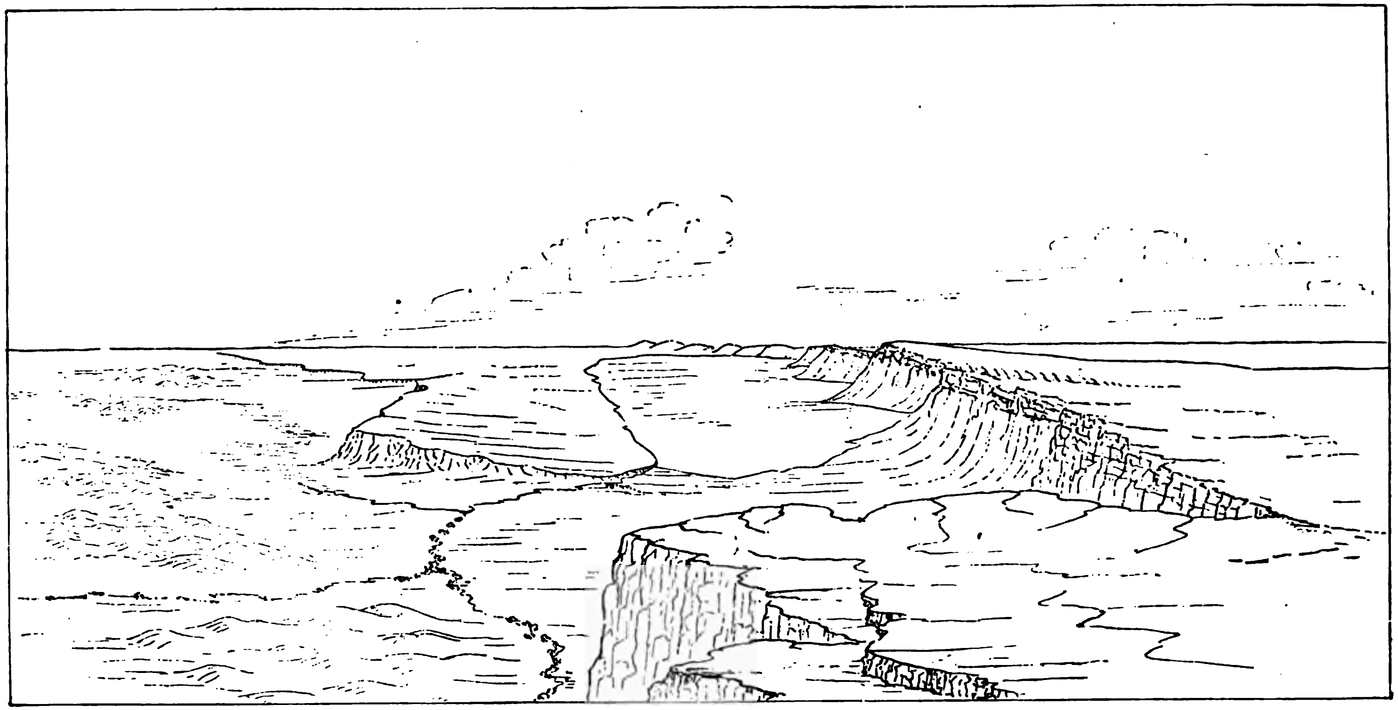
FIG. 10.—Sketch section through the northern part of Warner Lake Valley, Oregon.

In the southern part of the Warner Lakes Valley the structure is more complex, as the basin is bounded on each side by perpendicular cliffs of displacement, from 1,500 to 2,000 feet high, while the included area is broken by both north-and-south and east-and-west faults. A sketch section, taken a few miles south of Crook's Bridge, shows the following displacements:

FIG. 11.—Sketch section through the southern part of Warner Lake Valley, Oregon.

It is between the high walls inclosing the southern portion of the valley that the greatest confusion of the minor blocks is to be seen. Many of these fragments measure a mile or so on their edges, and are tilted in various directions, leaving narrow rugged valleys between their upturned margins. The diverse tilting and the numerous fault-scarps that rise without system into naked precipices combine to make this a region of the roughest and wildest description.

The mountain-mass, forming the western border of Warner Valley below Crook's Bridge, is bounded on the west also by a steep scarp that is probably the result of faulting. The fault-scarp overlooking the Warner Valley is about 2,000 feet high; and the opposite or western side of the block presents a face of equally grand proportions. The block thus defined is bounded in part by east-and-west faults and some-



SKETCH OF ABERT LAKE, OREGON.

what dissected by erosion. When viewed from a point a few miles to the northward it is seen to have a concave surface, and in fact forms a broad and extremely gentle synclinal. On its surface is a group of volcanic buttes of earlier date than the displacements that produced the dominant features in the present topography.

The narrow zone of displacement forming the valley of the Warner Lakes is continued southward, and produces the most striking features in the topography of Long Valley. It is probable also that the Surprise Valley zone of displacement is a portion of the same system, although the connection between the two has not been traced. The Warner Valley zone, together with its extension through Long Valley, is over 100 miles in length, and is perhaps the most remarkable example of compound faulting that has ever been reported. The occurrence of hot springs about the Warner Lakes may be taken as an indication that orographic movement has taken place beneath the valley at a recent date, but this hypothesis lacks the confirmation which would be afforded by the association of recent fault-scarps with the springs.

The rocks throughout this region include basalts, rhyolites, and light-colored volcanic tuffs, that are quite regularly bedded, and appear as definite strata in the palisade walls. None of the beds, however, are known to be sufficiently constant to be used as data for measuring the amount of displacement or for connecting the exposures in various cliffs. A heavy stratum of dark volcanic rock that caps the cliffs over a wide area, and is frequently a conspicuous feature in the landscape, has gained for this region the name of the "Rim-Rock country."

The only measure we have for the displacement that has taken place is furnished by the fault-scarps still remaining. These, as they stand to-day, without noting the amount removed by erosion, or the depth of the lake-beds obscuring their bases, range from a few hundred to fully 2,000 feet in height.

THE ABERT LAKE FAULT.

The grand cliffs that present an impassable barrier along the eastern shore of Abert Lake expose the broken edges of the strata on the heaved side of a fault; while the thrown side underlies the lake-basin and forms the gently sloping western shore. A short distance south of the lake the great fault divides, and sends a branch to the northwestward which determines the northeastern border of the Chewaucan Marsh, while the main fault-scarp continues on, as we have said, to form the eastern border of Abert Lake. The triangular block included between these two faults inclines to the eastward, and has been so depressed along the margin adjacent to the great fault as to form the basin now

occupied by the lake. The character of these fractures, and of the tilting of the included block, may be gathered from the accompanying sketch, taken at the southern end of the lake near where the fault divides. An ideal section from east to west through Abert Lake is given below, and will assist in interpreting the sketch.

FIG. 12.—Sketch section through Abert Lake Valley, Oregon.

Each of the faults bounding Abert Lake has a curved and irregular course, and finally becomes lost in branches as we follow it northward. The large branching fault determining the western boundary of the orographic block crosses the stream draining from the Chewaucan Marsh to Abert Lake near its mouth. The water flows from the thrown to the upheaved side of the fault, and is consequently ponded by the fault-scarp, and gives origin to the marsh, which is in fact a lake that has been nearly obliterated by sedimentation. Where the Chewaucan River crosses the fault-scarp, it forms a series of picturesque rapids with a fall of about 50 feet.

The palisade rising abruptly from the eastern shore of Abert Lake has a deep brownish tone, relieved by a growth of bright yellow lichens, and is grand in its barren ruggedness, especially towards evening, when its inherent richness of color is heightened with sunset tints. Near the top of the cliffs the hard layer, forming the "Rim-Rock," is a conspicuous feature, and in resisting erosion has no doubt done much towards preserving the sharp outlines of the cliffs.

THE SUMMER LAKE FAULT.

The irregular mountain face overlooking Summer Lake on the west is the upheaved side of a great fault, the throw of which is not less than 2,500 or 3,000 feet. From the top of the scarp the country inclines gently westward, and forms a well-wooded, sloping table-land. The southern extension of the fault may be traced along the western border of the Chewaucan Marsh, but its entire extent in that direction is unknown. In the northern part of its course it curves eastward, and divides into a number of branches near the northern end of the lake. A continuation of the same fault, or a branch from it, appears again along the shore of Silver Lake.

At many localities near the base of the cliffs which determine the western shore of Summer Lake, we find that a very recent movement has taken place along the ancient fault-line. Its course is marked by fresh

slopes of earth and gravel, and by irregular piles of *débris*, that are separated from the base of the cliffs by sunken areas. At a number of points near the recent fault-scarp springs come to the surface, many of them being of large size, and a few showing a temperature above the normal.

In some places on the eastern border of Summer Lake Valley there are abrupt precipices, apparently due to faulting; but in general, the country has a gentle inclination lakeward, thus indicating that the water covers the depressed edge of a large orographic block.

THE SURPRISE VALLEY FAULT.

Another line of profound displacement, which has resulted in the upheaval of one of the grandest of the Basin ranges, is the fault that determines the western border of Surprise Valley. The country affected by this displacement lies mostly in California, and was visited by the writer during a previous reconnaissance.

Structurally, Surprise Valley is a narrow north and south zone of diverse displacement, similar in many of its features to the valley of the Warner Lakes. The main fault follows the immediate western edge of the plain, although branches are thrown out across the valley at both the southern and northern ends. At the southward this fault is first recognized on the west side of Duck Flats, and may be followed northward, with increasing displacement, to the base of Eagle Peak, which rises to an elevation of more than 4,000 feet above the valley, and thence to a point a few miles beyond Camp Bidwell. When studied more accurately, it will probably be found to form a branch of the Warner Lake zone of displacement, and it may have other connections with the interlacing fractures of the Great Basin. The fault-scarp forming the eastern slope of the Warner Mountains has been carved by stream erosion, and sculptured by rain, wind, and frost, into deep recesses, outstanding pinnacles, and lofty domes, that combine to form a grander and more varied mountain mass than the palisades overlooking Summer, Abert, and Warner Lakes. Considered from an artist's standpoint, the scenery of the Warner Range compares favorably with the bold western slope of the Wahsatch Mountains, and is certainly far grander than the majority of the desert ranges of Utah and Nevada. From the amount of erosion that has taken place in the Warner Mountains, it seems evident that the upheaved block from which they have been sculptured has been longer exposed to denudation than the fault-scarps to the northward.

This line of displacement is marked by numerous hot springs and by fresh fault-scarps, from 20 to 50 feet high, that cross alluvial cones, and cut embankments and terraces of Quaternary age, telling in the plain-

est language that the rocks bordering the line of fracture have been disturbed at a very recent date, and that the Warner Mountains are young, and probably still growing. That the fault movement is paroxysmal is indicated by the earthquakes which are sometimes felt throughout the valley.

The cliffs bordering Surprise Valley on the east are apparently due to a displacement along a branching facture. This, in its turn, throws off several smaller faults, which radiate, like the rays of a partially open fan, from a point on the eastern shore of Middle Lake. Near where these fault-lines diverge there are copious springs having a temperature of 180° F., that rise through the fissures produced by the displacement. The branching faults cut out long, monoclinal blocks, that become less disturbed as we trace them northward, and finally merge with the general surface of the volcanic table-land from which they were fractured. A sketch section across the southern end of the valley is given in Fig. 13; and in Fig. 14 we have a similar ideal diagram of the faults at the northern end of the valley.

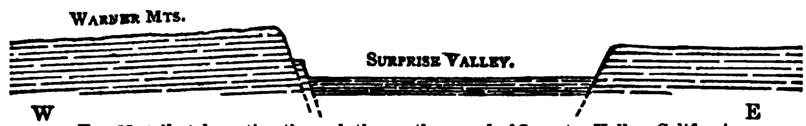


FIG. 13.—Sketch section through the southern end of Surprise Valley, California.

The Warner Range, like nearly all the mountains in the region explored, is composed of volcanic rocks of various kinds, including principally rhyolites, basalts, and volcanic tuffs. Before the commencement of the faulting that gave birth to the present topography of Surprise

FIG. 14.—Sketch section through the northern part of Surprise Valley, California.

Valley, the region must have formed a part of the great volcanic tableland of southern and central Oregon, and northern California. Its character before the fracturing took place is illustrated, except in the features due to modern erosion, by the rugged, volcanic region known as the Madeline Mesa, lying between Surprise Valley and the Black Rock Desert.

SUMMARY OF OBSERVATIONS RELATING TO DISPLACEMENTS.

Regarding the date of the displacements in the northern part of the Great Basin, we find them breaking rocks of all ages, from what we may consider, at least provisionally, as Eozoic granites—through Palæo-

zoic and Tertiary beds and Quaternary lake-sediments. In some instances the shearing has been continued through recent alluvial slopes and stream beds, and is without question still in progress. The Quaternary strata, however, are not upturned on the mountain flanks, while the sediments of the Tertiary lakes are thus inclined. From the evidence now in hand it would seem that the faulting commenced in late Tertiary time, and has been continued to the present day. Previous to the inception of the faults there were many successive overflows of volcanic rock, aggregating thousands of feet in thickness. There were lakes resting on floors of lava that became filled with volcanic lapilli, which in turn were buried by later volcanic overflows. The volcanic lapilli in many instances became stratified through the agency of the water in which they fell, and, somewhat altered and consolidated, they now appear as many-tinted volcanic tuff. Although thousands of square miles of "lava country" have been more or less thoroughly explored in Idaho, Washington, Oregon, Nevada, and California, we do not yet know the limits of the vast volcanic region of which the desertsof Oregon are a fraction; but its extent has been estimated by Prof. Joseph Le Conte at from 200,000 to 300,000 square miles.(*a*) The lakes in which the evenly stratified tuffs were spread out appear to have been of proportionally grand dimensions, although their outlines are unknown. The age of the volcanic overflows and of the intercalated beds of tuff has been stated by Professor Le Conte to be Tertiary, and probably Miocene.(*b*) After these vast fields of lava had cooled and consolidated, there came another revolution that affected a region equally great but situated mostly to the southward of the volcanic overflows. A force, or series of forces, the power and extent of which are utterly beyond the limits of our conception, was brought into action over a region at least 250,000 square miles in area, and broke the earth's crust into thousands of fragments, which were depressed and buried, or upheaved into mountain ridges. The cause of this vast deformation is a problem yet unsolved; at present we are only gathering the facts which, it is hoped, will lead to its interpretation.

The data now in hand bearing on the later physical history of the Great Basin may be briefly summarized as follows:

The fracturing has affected the whole great area between the Sierra Nevada and Wahsatch mountain-systems. The fault along the western base of the Wahsatch Range, and the equally profound displacement at the eastern base of the Sierra Nevada and Cascade Range, belong to the Great Basin system.

The orographic blocks are long and narrow, sometimes in the ratio of 50 to 1, or even more.

The general bearing of the longer axes is approximately parallel to the trend of the inclosing mountain ranges, *i. e.*, north-northeast.

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a American Journal of Science, III., Vol. VII., No. 39 (March, 1874), p. 168.
b Loc. cit., p. 177.

The average elevation of the area of displacement is from 3,000 to 5,000 feet lower than the mountain ranges that inclose it; and over a large area in Utah and Nevada it has an elevation of about 4,000 feet above the sea.

The great faults at the bases of the Wahsatch and the Sierra Nevada, as well as very many of the intermediate lines of fracture, have increased their displacement during the past few years; and, without question, these orographic movements are still in progress throughout the Great Basin.

Volcanic, metamorphic, and sedimentary beds have been fractured and displaced alike.

The high temperature of many of the springs that come to the surface along lines of recent displacement is apparently due to the heat produced by the arrested motion of the orographic blocks. Conversely, when we find hot springs at a distance from volcanic centers, especially if they occur in a linear series, we may presume that they mark a line of recent faulting.

The hade of the faults is nearly always towards the thrown side, and is usually steep, an inclination of from 40° to 70° with a horizontal plane being the most common. The faults are irregular with reference to both horizontal and vertical planes, and are frequently curved. When the fault lines curve, they are usually concave toward the thrown side. When the larger faults branch, the branches are usually on the thrown side. Zones of diverse displacement are usually depressed areas. The disturbance is almost always by fracture, and seldom by flexure. The orographic blocks are strictly monoclinal, and in no way can they be considered as portions of anticlinals or synclinals.

The present topography of the Great Basin has been imposed upon a far older structure, in which plication was one of the principal elements.

The greatest depression has taken place along the east and west borders of the basin. The eastern depression was occupied during the Quaternary by Lake Bonneville, and that on the western border by Lake Lahontan. In some instances the total faulting resulted from small and sudden displacements, as at the time of the earthquake in Owen's Valley in 1872.

The tilted blocks occupy more horizontal space than they did before the faulting took place.

In a general discussion of the faults of the Great Basin, the most important facts to be kept in view are that the region is one of elevation with reference to the sea-level, but of depression when referred to its immediate boundaries, and that the orographic blocks in their present tilted condition occupy more horizontal space than they did before the faulting took place.

The investigator should also observe that the displacement is by simple faulting, and never—so far as present observations extend—by flexing. We find the reverse of these conditions in regions like the Alle-

ghanies and the Alps, where the strata have been folded and crumpled on a grand scale. In such instances, as is well known, the rocks occupy less horizontal space than previous to their disturbance, and have therefore undergone *lateral compression.* In view of these facts the suggestion presents itself that the faulting in the Great Basin is associated with *lateral extension.* The Cordillera system of the west coast is a region of upheaval, as its present altitude testifies. In other words, it is the segment of a spherical surface, the radius of which has been increased. The boundaries of the segment are mountain ranges of great magnitude, while the included region may be considered as a sunken and fractured plain. From these facts it seems fair to assume, at least as a provisional hypothesis, that the fractures are closely related to an extension of the strata, caused by upheaval, and that the displacement of the orographic blocks resulted from their gravity. If the elevation of the Cordillera system as a whole is the result of tangential strain, may we not consider the force as acting on the borders of the Great Basin, while the interior region subsided and was fractured *pari passu* as the rim was elevated?

The shifting of alluvium from one side of a fault-line to the other by erosion has been advanced as a cause explanatory of the movement of faults. Such a transfer of load is certainly in operation in many localities, and has much in its favor, when considered theoretically, as a cause of crust movement; yet it can have but little tendency to fracture the earth's crust into such ribbon-like bands as have been observed throughout the Great Basin. It can be readily seen that after a fault-scarp is formed the shifting of load from the upthrown to the downthrown side would tend to increase the displacement; and in case of great faults, like those determining the precipitous faces of the Wahsatch Range and Sierra Nevada, this factor certainly becomes of great importance. In the case of the narrow orographic blocks in the central portion of the Great Basin, the impression derived by the writer from a great number of observations is that this action is too slight to be an important element in the problem. In some instances the orographic movement is quite the reverse of what this hypothesis demands. On the Smoke Creek and Black Rock deserts a fault of post-Lahontan age may be traced for more than 50 miles across the former lake-bed at such a distance from mountains that no alluviation has taken place since the lake became dry. The thrown block is the one underlying the broad desert which was lightened prior to the recent movement of the fault by the removal of fully 500 feet of water. It is the unloaded block in this instance that has been depressed. Until quantitative observations have shown that the transfer of alluvium from the heaved to the thrown side of a fault, in a greatly disturbed region like the Great Basin, is in some cases sufficient to originate displacement, it seems safest to conclude that such action is only an incidental and concomitant result of the faulting, tending, it is true, to increase displacement already initiated.

The lakes of the present day in the Great Basin, north of the hydrographic rim of Lake Lahontan, are shown on the accompanying map (Plate LXXXIII). All of these are small and shallow, and in a number of instances may be classed as playa-lakes, as their waters evaporate to dryness during arid seasons, leaving mud plains or playas to mark their sites.

Of the existing lakes in the region under discussion, those in the Klamath Basin alone overflow. The waters of the remainder are in nearly all cases somewhat alkaline and brackish, but, with the exception of Summer and Abert lakes, are sufficiently pure to afford watering places for stock, and in most instances may be used for culinary purposes, for a short time at least, without injurious effect.

Silver Lake, Oregon, is a remarkable exception to the rule that inclosed lakes are saline, as its waters are so fresh that scarcely a taste of mineral matter can be detected. Its freshness is the more remarkable, as it is situated in the basin of a Quaternary lake of broad expanse that was more than 100 feet deep and never overflowed. As shown by soundings made by Mr. Johnson in June, 1882, this lake has a uniform depth of 10 feet throughout nearly its entire extent.

Eagle Lake, in Lassen County, California, like Silver Lake, is an also exception to the usual saline condition of inclosed lakes, but in this instance the waters are supposed, with good reason, to escape through the gravels underlying the lava overflow which has checked the drainage of the valley.

Summer and Abert lakes are strong solutions of potash and soda salts. In their physical properties the waters of these lakes are very similar, and resemble the water of Mono Lake, California, but are far richer in potash salts, as is shown by the following analysis of the water of Abert Lake by Dr. F. W. Taylor, of the Smithsonian Institution, who reports as follows: (a)

Specific gravity, 1.02317.

One liter of the water contains—	Grams.
Silica in solution	0.065
Sodium chloride	7.219
Potassium chloride	8.455
Potassium sulphate	0.921
Potassium carbonate	10.691
Magnesium carbonate	0.006
	27.357

No bromine nor iodine could be found in the sample analyzed.

a The sample analyzed was collected near the middle of the west shore of the lake, 500 yards from land.

The percentage of potassium salts shown by this analysis, amounting to about five-sevenths of the total solids, is higher than in any other lake the composition of which is known to us. The presence of so large an amount of highly soluble potassium salts might seem to indicate that the water is a mother-liquor from which the less soluble carbonate and sulphate of lime, sulphate of soda, and chloride of sodium had been crystallized out; and therefore that it is a residuum left after a long period of desiccation. The absence of iodides and bromides, however, and the paucity of magnesia, militates against this hypothesis, and as the latter salt especially would increase in percentage under the same conditions of evaporation that served to concentrate the potassium. As the volcanic rocks forming the hydrographic basin of the lake are largely composed of feldspars rich in potash, we may safely look to their disintegration and decomposition for the source of the mineral matter contained in the lake. It seems more probable that the large quantity of potash is due to abundant supply, rather than to the long concentration of water in which this salt was no more abundant than is ordinarily the case with river waters. This is the more evident, as the percentage of saline matter in the lake is smaller, and its constituents exhibit less variety than we might reasonably expect if the lake had undergone a long period of concentration.

Although both Summer and Abert lakes are alkaline solutions, with shores as barren and desolate as the borders of the Dead Sea, yet they have many features that are attractive and picturesque, and furnish a striking contrast to the forest-bordered lakes of humid climes. In summer their peculiar glassy surfaces mirror with great distinctness the azure of the cloudless sky, and the rugged grandeur of the cliffs that overshadow them. Their waters are so strongly charged with salts that they are uninhabited by fish, but swarm with millions of small crustaceans of the genus *Artemia*, known commonly as "brine-shrimps." When swept by the tempests, these alkaline waters are soon churned into great fields of foam, sometimes several feet in depth, that is caught up by the wind, and carried in thousands of fleecy masses far up the shores. Becoming entangled amid the desert shrubs it gives them the appearance of being covered with a profusion of strange blossoms. The tendency of alkaline waters to form fields of foam when disturbed by the wind may also be observed at the Soda Ponds, near Ragtown, Nevada, and still better at Mono Lake, California.

Of the lakes in the region explored that have the characteristic features of playa-lakes, the following are examples: Alvord, Guano, Massacre, Warner, and Christmas lakes, together with the lakes of Surprise and Long valleys. These are shallow-water sheets that occupy depressions in lake-sediments, and are usually surrounded by low shores which are not unfrequently white with drifting alkali. Their waters are alkaline, and usually of a greenish yellow color, due to impalpable silt held in suspension. During unusually arid seasons they become

completely desiccated, leaving mud-plains or salt-fields as records of their former extent.

The larger lakes, as Goose, Summer, Abert, Silver, and Malheur, although they have never been known to become dry, are extremely shallow, and during a succession of arid seasons would unquestionably evaporate completely. Excepting the Klamath Lakes, of which no reliable soundings are at hand, the deepest of the existing lakes north of the Lahontan hydrographic basin is Goose Lake, which throughout its entire area does not exceed 20 feet. Summer and Abert lakes have an average depth of less than 10 feet, and in the remaining basins the water is even more shallow.

The lakes of Southern Oregon, like those of all inclosed basins, record the quantitative relation of precipitation to evaporation; and vary with the seasons, not only in extent and depth, but in percentage of saline matter as well. During the summer and fall, when precipitation is at a minimum, and evaporation is rapid, they decrease in extent and depth, while the density of their waters increases.

They vary also from year to year, rising when the rainfall exceeds the average and falling when it is deficient. The depths here noted apply to the summer of 1882.

RECENT CHANGES IN EXISTING LAKES.

One of the most interesting of the recent changes in the extent of the lakes in the region embraced in our reconnaissance is the union of Harney and Malheur lakes. Previous to a season of unusual humidity about the year 1877, these lakes were separated by an embankment of gravel—probably a bar built by the waves and currents when the water was deeper than at present—which was breached during the season of high-water, causing the lakes to be united. The present combined water surface retains the name of Malheur Lake.

Persons who have been familiar with Silver Lake since 1870 have never known it to become dry; its present freshness, however, would indicate that such an occurence took place not many years since, as inclosed lakes are supposed to be freshened by desiccation. During the past three years its waters have risen about six feet and flooded large areas, that previous to 1879 were meadow-lands and pastures. Owing to this recent rise, Thorn and Silver lakes are now confluent. The difference between the winter and summer horizons of the lake's surface is about two feet.

Goose Lake has not overflowed, except during a single storm, since 1869. For a term of years prior to that date, it waters were much lower than at present, as is shown by the fact that a road then crossed the lake-basin some four or five miles from its southern end at a place which

is now covered by 15 feet of water. During the past few years it has been rising, and in 1881 it is reported to have overflowed for two hours, or more, during a severe gale from the north.

Horse Lake is a small playa-lake, situated in the eastern border of California, between Honey Lake Valley and the Madeline Plains. Its ancient channel of overflow is carved through a volcanic mesa, and joins Snowstorm Cañon. In 1868 the lake rose sufficiently to overflow and send some tribute to Honey Lake through its long-abandoned channel. The bottom of the outlet is about ten feet above the usual level of the lake, showing that the high water of 1868 was considerably more than the ordinary winter's rise. The lake became dry in the summers of 1878 and 1879, its bottom forming a hard, smooth, mud plain.

The lakes now filling shallow depressions in Surprise Valley are typical examples of playa-lakes. During extremely dry seasons they become completely desiccated, and leave either fields of salt or playas of cream-colored mud. The Upper Lake became dry in the summers of 1872 and 1873, leaving a broad mud-plain that was soon whitened with a saline efflorescence. From the above date to the present time it has always contained some water. The Lower Lake was last completely desiccated about ten years since, when it deposited a large quantity of tolerably pure salt.

These changes are not only interesting examples of the fluctuations of inclosed lakes, but, when taken in connection with the rise and fall of other lakes throughout the Great Basin, will assist in determining the variations in humidity to which the region is subject. When sufficient observations are in hand they may also enable us to predict the approach of a period more humid, or more arid, than usual. That the fluctuations of inclosed lakes are independent of the trifling changes that man, by his agricultural efforts, has produced in the character of the Great Basin, is shown by the rise and fall of such bodies of water as Silver Lake, Oregon; Pyramid, Winnemucca, and Walker lakes, Nevada; and Mono Lake, California, where the influence of man is wanting, or, if felt at all, is but slight, and can be shown to have had no appreciable effect on the climate of the region. Inclosed lakes are not only rain gauges that indicate approximately by their extent the abundant or meagre precipitation that takes place in their hydrographic basins, but they record also the balance between rainfall and evaporation. The study of these natural pluviometers teaches that the fluctuations of the lakes of the Great Basin during the past few years are but a continuation of the climatic oscillations that reached a maximum at the time Lake Bonneville and Lake Lahontan were brimming.

QUATERNARY LAKES.

The areas of depression mentioned when speaking of the great faults in Southern Oregon—of which the narrow faulted area along the eastern base of the Stein Mountains, and the zone of diplacement now occupied by the Warner Lakes, are typical examples—form orographic valleys, or rock basins, that were occupied by quite extensive lakes during the Quaternary period. Twelve of these ancient lakes claim our attention. As shown on the accompanying map (Plate LXXXIII), they occupied the valleys in which the following lakes occur at the present time, viz.: Alvord, Malheur, Warner, Guano, Summer, Abert, Silver, Goose, and Klamath, in Oregon, together with Surprise Valley and the Madeline Plains, in California, and Long Valley, Nevada. The first notable feature of their history is, that although some of them attained a depth of between 500 and 600 feet, yet only four overflowed. The lakes with outlets occupied the Malheur, Goose, and Klamath Basins, in Oregon, and the Madeline Plains, in California. In all of the other instances the inflow of water derived from rains, springs, and streams must have been counterbalanced solely by evaporation. All of these basins now hold shallow lakes, greatly inferior both in extent and depth to their Quaternary antecedents. The lakes which did not overflow must have become charged, to some extent at least, with saline matter, as their waters evaporated; which would lead us to expect that their modern representatives would be dense saline solutions. In only a single doubtful instance, however, can the lakes now occurring in these nearly desiccated basins be considered as the remnants left by incomplete evaporation of the Quaternary lakes. Summer and Abert lakes are dense saline and alkaline solutions (the analysis of the latter is given on page 454) that occupy depressions in the basin of a large Quaternary lake, and are, without question, the result of concentration by evaporation, but whether they have held their integrity since Quaternary times seems doubtful.

The extent and geographical distribution of the lakes that existed in the northern part of the Great Basin in Quaternary times may be gathered from the accompanying map (Plate LXXXIII). As the existing lakes are shown on the same illustration, the great contrast between the humidity of the region during the Quaternary and at the present day may be seen at a glance. In the instances in which the outlines of the Quaternary lakes are not known with certainty, their conjectural boundaries are indicated by dotted lines, as in the case of the Goose and Klamath basins. Our reconnoissance did not extend into the Klamath Basin, and what information we have in reference to its Quaternary his-

tory was kindly furnished by Lieut. E. A. Edwards, of Fort Klamath, or may be found in Dr. Newberry's geological report published in the sixth volume of the Pacific Railroad reports.

As the Quaternary lakes of the region explored were comparatively small, and sheltered in many instances by rugged cliffs, the action of waves and currents was restricted and embankments and bars of gravel seldom formed. The evidence of the existence of former lakes is mostly confined to wave-cut terraces, which record with unprejudiced accuracy the depth of the waters that carved them.

The deepest, and perhaps the most interesting, of these Quaternary lakes occupied Surprise Valley, California. In this instance the highest beach-line is a conspicuous feature throughout the valley, and is drawn as a contour-line on its sides at an elevation of 550 feet above the surface of the lake-beds that floor the basin. The former lake not only filled Surprise Valley, but overflowed across the narrow divide at its southern end, and covered Duck Flats as well. The lake thus formed was 70 miles long, with an average breadth of between 6 and 7 miles. There is evidence that it had two high-water stages, separated by a time of aridity when the valley was nearly, if not completely, desiccated.

The long narrow Quaternary lake east of the Stein Mountains, of which Lake Alvord is the diminutive representative, had a depth, over a large area, of 400 feet. The Malheur Basin at the same time was occupied by a broad but shallow sheet of water that overflowed into the Owyhee and excavated a broad channel of discharge. The ancient beach-lines left by the latter fossil lake are too indefinite to admit of determining its former depth.

In the valley of the Warner Lakes ancient beach-lines may be traced continuously about the borders of the basin at an elevation of 225 feet above the surface of the present playa-lakes. The outlines of the old lake are quite accurately shown on the accompanying map (Plate LXXXIII), and, as there indicated, are unbroken by a channel of overflow.

The Quaternary lake that occupied the valleys of Abert Lake, Chewaucan Marsh, and Summer Lake, was 260 feet deep over the Chewaucan Marsh, and 300 feet deep in the valley now occupied by Summer Lake.

Long Valley, now a desolate, level-floored, sage-brush plain, was occupied by a lake 250 feet deep in Quaternary times. Its modern representatives are small alkaline pools that usually become dry during the heat of summer.

The Quaternary lake that flooded the valley of Silver and Christmas Lakes had a depth of something more than 100 feet over a large area and formed an extensive water surface, as indicated on Plate LXXXIII. On following the ancient water-lines we find them continuous throughout, thus proving that the lake which formed them was without a channel of overflow.

In the northern extension of this old lake-basin, a few miles eastward of Christmas Lake, is a locality where considerable quantities of fossil bones have been found. This extinct fauna, comprising the elephant, camel, and horse, together with a large edentate, is strangely interesting when we remember the late date at which the animals lived, and the present desert character of the valley where their remains are found.(a) The bones occur on the surface of the lake-beds, detached from one another, and mingled with thousands of fresh-water shells. Among the fossil mollusks collected, the following species have been determined by Mr. R. Ellsworth Call, of David City, Nebr.:

Sphærium dentatum, Haldeman.
Pisidium ultramontanum, Prime.
Helisoma trivolvis, Say.
Gyraulus vermicularis, Gould.
Limnophysa bulimoides, Lea.
Carinifex Newberryi, Lea.
Valvata virens, Tryon.

Some of the fossil mollusks enumerated above are found in abundance in the sediments of Lake Lahontan, and all of the species are still living in the lakes and streams of the Pacific slope. In the lake-beds beneath the bones the shells of *Gyraulus vermicularis* occur in profusion to the depth of at least five or six feet, while the fossil bones were discovered only on the surface.

The bones collected at this locality are reported by Professor Marsh to be of Upper Pliocene age (Equus beds). In the determination of the age of the remains, there is certainly a discrepancy between the evidence derived from the vertebrate fossils on the one hand, and the testimony of the invertebrate fossils and the stratigraphical geology on the other—unless it can be shown that the fossil bones have been removed from their original place of interment and scattered over the bottom of the Quaternary lake. The bones are black, and considerably mineralized, and in general appearance seem older than any Quaternary fossils of the same class with which we are familiar. So far as this uncertain evidence goes, it favors the determination that the bones are of pre-Quaternary age, but is of little value in explaining this occurrence with a molluscan fauna of recent species.

Of the remaining Quaternary lakes represented on the pate, the one that covered the Madeline Plains, in Lassen County, California, is of interest from the fact that it was retained by a coulée of lava that had obstructed the drainage of the basin. The river formed by the discharge of this lake flowed southward across the lava-overflow, and carved Snowstorm Cañon.

Only one other basin that contained a lake of any considerable size

a A more complete list of vertebrate fossils from this locality is given by Prof. Cope, Amer. Naturalist, Vol. XII (1878), p. 125.

during Quaternary times remains to be mentioned. This is a long, narrow valley, named Guano Valley, which extends nearly due south from Beattie's Buttes, and is bounded on both the east and west by precipitous fault-scarps. Like the valley of the Warner Lakes, this depression was formed by the subsidence of a long, narrow orographic block, included between fault-lines. Guano Valley was examined by Mr. Johnson, who reports that it must have contained a shallow Quaternary lake. Beach lines were not observed, but owing to the shallowness of the water, and the precipitous nature of the shores, they could scarcely be looked for. The basin is completely inclosed by uplands, and no channel of discharge for the Quaternary lake was observed. Guano Valley, like nearly all the interior valleys of Southern Oregon, contains a playa-lake in a shallow depression in the surface of the lake-beds that floor the basin.

TUFA DEPOSITS.

Carbonate of lime in the form of tufa was found in a single one only of the old lake-beds. In Surprise Valley it occurs abundantly, both as a cement for the gravel of the ancient beaches, and as a deposit about stones and pebbles that were lying at the bottom of the lake when the waters evaporated away for the last time. The pebbles partially buried in lake-beds frequently support mushroom-shaped growth of tufa several inches high. These curious forms occur in abundance in the narrow channel that connects Surprise Valley with Duck Flats, and when calcined they form an excellent lime.

The basins that we have briefly described comprise all the noteworthy hydrographic areas of the Great Basin north of the hydrographic rim of Lake Lahontan.

RÉSUMÉ.

The events in the later geological history of the portion of the Great Basin embraced within our reconnaissance may be briefly summarized as follows:

The rocks are almost entirely igneous, and occur on the southern border of an immense volcanic region that stretches indefinitely northward.

The basins are orographic valleys of the Great Basin type, and were formed by the tilting of orographic blocks.

During the Quaternary the excess of precipitation over evaporation was greater than at present. This is shown by the size of the drainage channels, now partially filled with alluvium, and the extent and depth of the Quaternary lakes, as compared with their modern representatives.

A number of the Quaternary lakes did not overflow, their influx being counterbalanced solely by evaporation, thus indicating that precipitation was not excessive.

Many of the lakes which now occupy the basins of extensive Quaternary lakes that did not find outlet, are either fresh, or hold but a small amount (a fraction of one per cent.) of mineral matter in solution. These lakes, of which Alvord, Warner, Silver, and Christmas, together with those of Surprise Valley, are examples, can in no way be considered as remnants left by the incomplete evaporation of the Quaternary lakes which they respectively represent.

Summer and Abert lakes are more strongly charged with potash salts and chloride of sodium, and owe their high percentage of saline matter to the concentration of the waters of streams and springs which are ordinarily spoken of as fresh.

The Quaternary lakes which occupied the Malheur, Klamath, and Goose Lake basins, overflowed, and became tributary to the ocean, while the water-body covering the Madeline Plains discharged into Lake Lahontan. The present lakes occurring in these basins do not differ materially from the waters now found in the basins that have not overflowed. This similarity may be explained by assuming that the inclosed lakes have at no distant date, and probably at a number of separate periods, been evaporated to dryness, and their saline contents buried beneath playa-mud so completely that the waters subsequently filling the basin did not take them into solution.(*a*)

a The hypothesis of the freshening of inclosed lakes by desiccation was first proposed by Mr. Gilbert during his study of Lake Bonneville. Second Ann. Rep. U. S. G. S., p. 177.

The evidence of climatic changes during the Quaternary, as exhibited in the histories of Lakes Bonneville and Lahontan, has already been published, and one looks with interest to the smaller contemporary lakes for the confirmation and extension of this record. As will be remembered, the fluctuations of the larger lakes prove that the Quaternary was ushered in by a long period of aridity, followed by a humid and probably glacial period, during which Lahontan became nearly 900 feet deep, and Bonneville rose still higher. Next succeeded an arid period, where both lakes became greatly reduced by evaporation and perhaps completely desiccated. Following this was a second cold and humid period, of short duration, but of great intensity, as compared with the first; and finally came the present dry climate. These fluctuations of the geological hygrometer, as recorded by the larger Quaternary lakes of the Great Basin, are indicated in the following diagram:

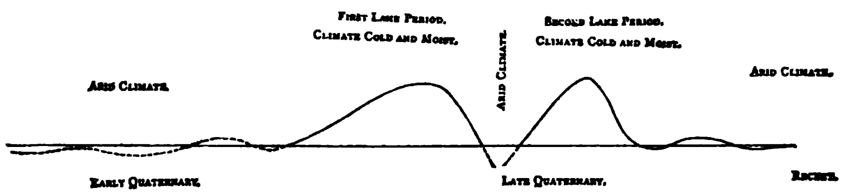

FIG. 16.—Curve of Quaternary climatic oscillations.

In the smaller lake basins of southern Oregon it has been impossible to decipher the Quaternary history with as much detail as in the case of the larger contemporary lakes to the southward. In Surprise Valley, however, we have the records of two high-water periods, divided by a time of low water, but the proof of these changes is not as satisfactory as could be desired. In the field of our reconnaissance the observation having the greatest bearing on Quaternary climate is that many of the basins occupied now by arid deserts were then filled with lakes.

The geological history of the region examined gives but slight information as to the temperature of the Quaternary period. The fact that the smaller lakes formed wave-built and current-built embankments proves that they were not frozen (although they were but shallow water-bodies) during at least a portion of their existence. The absence of ice ridges about their borders is negative evidence that the climate of the period was not excessively cold. As the records of local glaciers,[a] and even of a general northern ice-sheet,[b] have been reported from this region by observers whose opinions are entitled to respect, it is proper to state that I found no evidence either of local glaciers, nor of general glaciation. Evidence of glaciation was looked for with care,

[a] "On the Puebla Range of Mountains," James Blake. Proc. Cal. Acad. Sci., vol. 5, p. 212.

[b] "On the Great Lava Flood of the Northwest," etc., Joseph Le Conte. Am. Jr. Sci., III., vol. 7, No. 40 (April, 1874).

and I feel safe in concluding from its absence, that no glaciers existed during the Quaternary in that part of Oregon east of the Cascade Mountains and south of the forty-fourth parallel. As my geological studies have led me over a large portion of the northern half of the Great Basin, I may add my testimony to the observations already recorded which show that the mountains of the Great Basin, with the exception of the East Humboldt—and less positively of two or three associated ranges—have been free from glaciers, at least since the country had its present topography.(*a*) As is well known, the Wahsatch range and Sierra Nevada gave origin to local glaciers, which flowed down their sides in rivers of ice, sometimes a number of miles in extent. The records of a general ice-sheet covering the northern part of the Great Basin are totally absent.

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a So far as my own observations extend, the East Humboldt are the only mountains between the Sierra Nevada and Wahsatch that bear marks of glaciation.

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A geological reconnaissance in southern Oregon.
TITLE

DATE DUE	BORROWER'S NAME

DATE DUE
